THE UNIVERSITY OF BRITISH COLUMBIA
Department of Chemistry
Chemistry 121 Midterm Examination

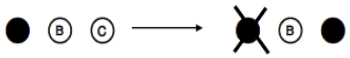
October 10, 2017 Time Limit: 60 minutes

INSTRUCTIONS:

1. Check that this examination paper consists of **12 pages total, printed on both sides**.
2. Answer all questions on the separate bubble sheet provided.
   Any answers written on this examination paper will NOT be graded.
3. The last page of this examination paper is a sheet of supplementary information and the Periodic Table. You may detach this page.
4. The only calculators permitted are the Sharp EL−510 series. All other calculators will be confiscated by the invigilators.
5. Unassembled model kits are allowed. Models cannot have writing/marks on them. Instruction sheets are NOT permitted.
6. No electronic communication devices are permitted on writing desks. Your electronics must be powered off and out of reach.
7. When handing in your exam, please place all loose pages inside the examination paper. This examination paper **will NOT be returned**.
8. **Do NOT fold** the bubble sheet.
9. For bubble responses, *completely* fill in the bubble in dark pencil or ink and leave the rest blank:

Selecting option "D"

10. If you've written in pen and want to change your response, then draw a neat "X" over the response you do NOT want marked and fill in your new response.



Pen: Changing an answer from "A" to "C"

RULES GOVERNING FORMAL EXAMINATIONS

1. Each examination candidate must be prepared to produce, upon the request of the invigilator or examiner, his or her UBCcard for identification.
2. Examination candidates are not permitted to ask questions of the examiners or invigilators, except in cases of supposed errors or ambiguities in examination questions, illegible or missing material, or the like.
3. No examination candidate shall be permitted to enter the examination room after the expiration of one-half hour from the scheduled starting time, or to leave during the first half hour of the examination. Should the examination run forty-five (45) minutes or less, no examination candidate shall be permitted to enter the examination room once the examination has begun.
4. Examination candidates must conduct themselves honestly and in accordance with established rules for a given examination, which will be articulated by the examiner or invigilator prior to the examination commencing. Should dishonest behaviour be observed by the examiner(s) or invigilator(s), pleas of accident or forgetfulness shall not be received.
5. Examination candidates suspected of any of the following, or any other similar practices, may be immediately dismissed from the examination by the examiner/invigilator, and may be subject to disciplinary action:

   i. speaking or communicating with other examination candidates, unless otherwise authorized;
   ii. purposely exposing written papers to the view of other examination candidates or imaging devices;
   iii. purposely viewing the written papers of other examination candidates;
   iv. using or having visible at the place of writing any books, papers or other memory aid devices other than those authorized by the examiner(s); and,
   v. using or operating electronic devices including but not limited to telephones, calculators, computers, or similar devices other than those authorized by the examiner(s)—(electronic devices other than those authorized by the examiner(s) must be completely powered down if present at the place of writing).

6. Examination candidates must not destroy or damage any examination material, must hand in all examination papers, and must not take any examination material from the examination room without permission of the examiner or invigilator.
7. Notwithstanding the above, for any mode of examination that does not fall into the traditional, paper-based method, examination candidates shall adhere to any special rules for conduct as established and articulated by the examiner.
8. Examination candidates must follow any additional examination rules or directions communicated by the examiner(s) or invigilator(s).

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You may use it for rough work.

PART I. Multiple Choice [32 marks total]

For each numbered statement below, identify the letter that corresponds to the best answer. There is only one correct answer per question. Record your responses ***on the separate bubble sheet***. Only responses given on the bubble sheet will be marked.

1. **[2 marks]** Arrange the following atoms (from molecules) in order of increasing electronegativity.

   A. Al < C < Si < S < Cl
   B. C < Al < S < Si < Cl
   C. Cl < C < Si < Al < S
   D. Al < Si < C < S < Cl
   E. C < Al < Si < Cl < S

2. **[2 marks]** Which of the following ionic compounds is expected to have the smallest lattice energy?

   A. KBr
   B. NaCl
   C. BaS
   D. LiF
   E. ScN

3. **[2 marks]** The C–O bond order for the carbonate anion, $[CO_3]^{2-}$, (C is the central atom) is best described as:

   A. between 0 and 1
   B. exactly 1
   C. between 1 and 2
   D. exactly 2
   E. between 2 and 3

4. **[2 marks]** Which of the following molecules has a trigonal planar molecular shape and a net dipole moment? The central atom in each molecule is underlined.

   A. $\underline{P}Cl_2F$
   B. $\underline{B}F_3$
   C. $\underline{Br}F_3$
   D. $\underline{S}O_3$
   E. $\underline{C}H_2O$

5. **[2 marks]** Which of the following compounds has a seesaw molecular shape? The central atom in each molecule is underlined.

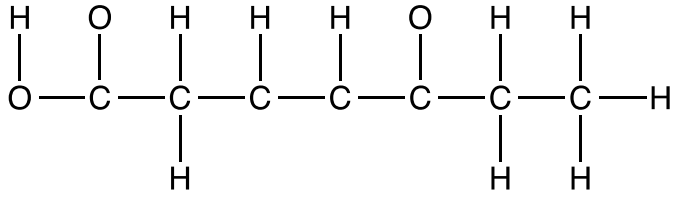
   A. $\underline{P}H_3$
   B. $\underline{Al}Cl_3$
   C. $\underline{As}F_3$
   D. $\underline{Te}Cl_4$
   E. $\underline{C}H_2O$

6. **[2 marks]** Consider the best Lewis structures for perchlorate $[\underline{Cl}O_4]^-$, chlorate $[\underline{Cl}O_3]^-$, and chlorite $[\underline{Cl}O_2]^-$. The central atom in each ion is underlined. Which of the following is **TRUE**?

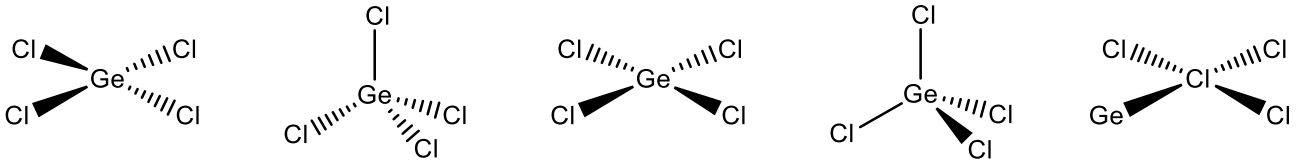
   A. All have at least one lone pair of electrons on the central chlorine atom.
   B. All have tetrahedral molecular shape.
   C. All have two double bonds.
   D. All have the same oxidation state for chlorine.
   E. All have one oxygen with a formal charge of -1.

7. **[2 marks]** What is the <u>maximum</u> number of atoms that can lie in the same plane in the following molecule? Only atom connectivity is shown. Multiple bonds and lone pairs of electrons are omitted.

   A. 10
   B. 12
   C. 14
   D. 16
   E. 20



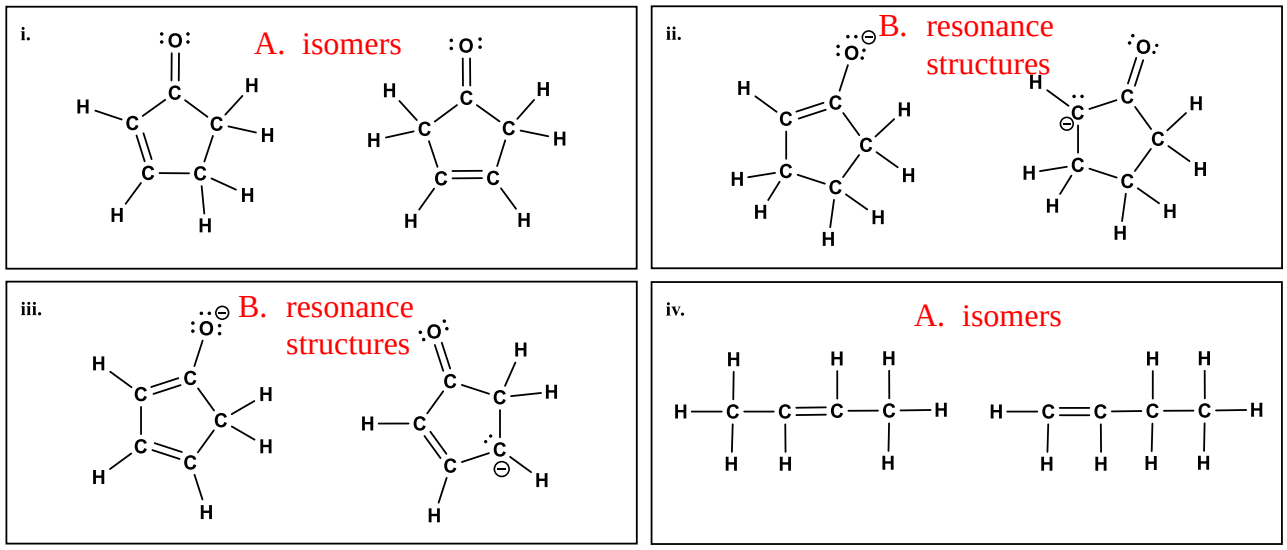
8. **[2 marks]** Which of the following is a correct perspective diagram of $GeCl_4$?



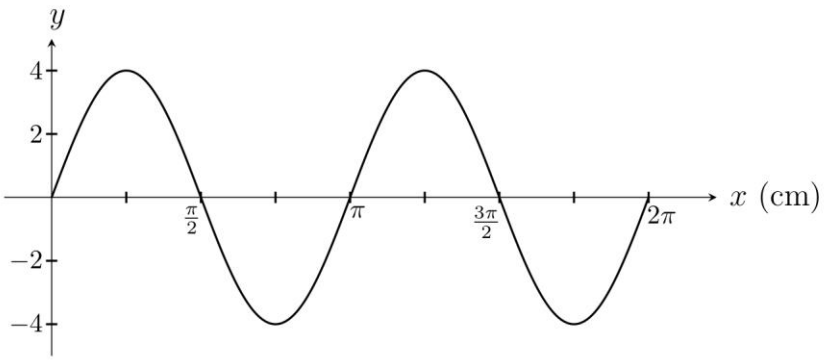
A. B. C. D. E.

9. **[4 marks]** For each part, i-iv, classify the pair of molecules below as:

   A. isomers
   B. resonance structures



10. **[2 marks]** What are the amplitude and wavelength of the following wave?



i. The amplitude is:

A. 2
B. 4
C. 8
D. π
E. 2π

ii. The wavelength (in cm) is:

A. 2
B. 4
C. 8
D. π
E. 2π

11. **[2 marks]** What is the de Broglie wavelength of a hydrogen (^{1}H) atom with a speed of 5.0 x 10^6 m/s?

A. 7.9 x 10^{-14} m
B. 1.7 x 10^{-14} m
C. 9.1 x 10^{-15} m
D. 8.7 x 10^{-15} m
E. 2.6 x 10^{-15} m

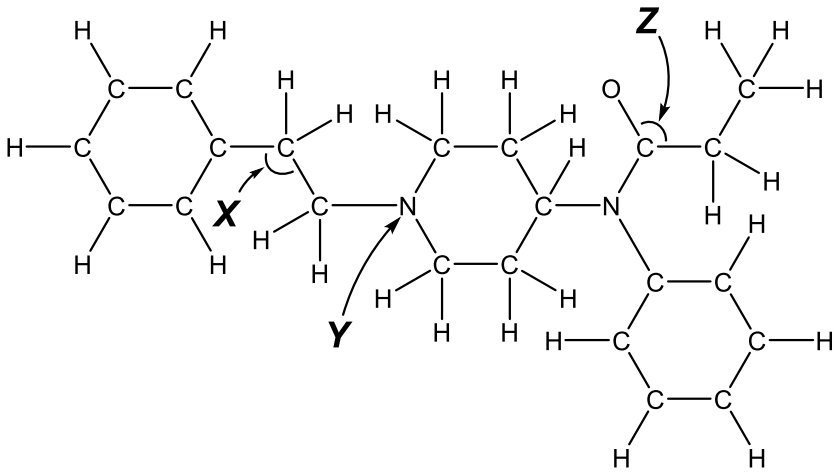
12. **[2 marks]** A standing wave has 7 nodes inside a box 24.0 cm in length. What is the wavelength, λ, of the standing wave?

A. λ = 0.292 cm
B. λ = 2.00 cm
C. λ = 3.00 cm
D. λ = 3.43 cm
E. λ = 6.00 cm

13. **[2 marks]** Which one of the following statements is **TRUE** regarding a quantum particle in a one-dimensional box?

A. The observed energy of the particle is quantized because the particle is confined.
B. If the particle has the lowest energy, it is always found in the middle of the box.
C. There is only one physical solution to the Schrodinger equation.
D. The ground state wavefunction has one node.
E. The lowest energy of the particle is zero.

The skeletal structure of an organic molecule is shown below. Multiple bonds, lone electron pairs, and formal charges are not shown. Use the best Lewis structure of this molecule to answer questions 14 through 17.



14. **[1 mark]** The estimated C–C–C bond angle labeled ***X*** is:

A. 90°
B. 109.5°
C. 120°
D. 135°
E. 180°

15. **[1 mark]** The molecular shape at the nitrogen atom labeled ***Y*** is:

A. bent
B. linear
C. tetrahedral
D. trigonal planar
E. trigonal pyramidal

16. **[1 mark]** The estimated O–C–C bond angle labeled ***Z*** is:

A. 72°
B. 90°
C. 109.5°
D. 120°
E. 135°

17. **[1 mark]** The total number of carbon atoms with tetrahedral molecular shape is:

A. 8
B. 9
C. 14
D. 20
E. None of the above

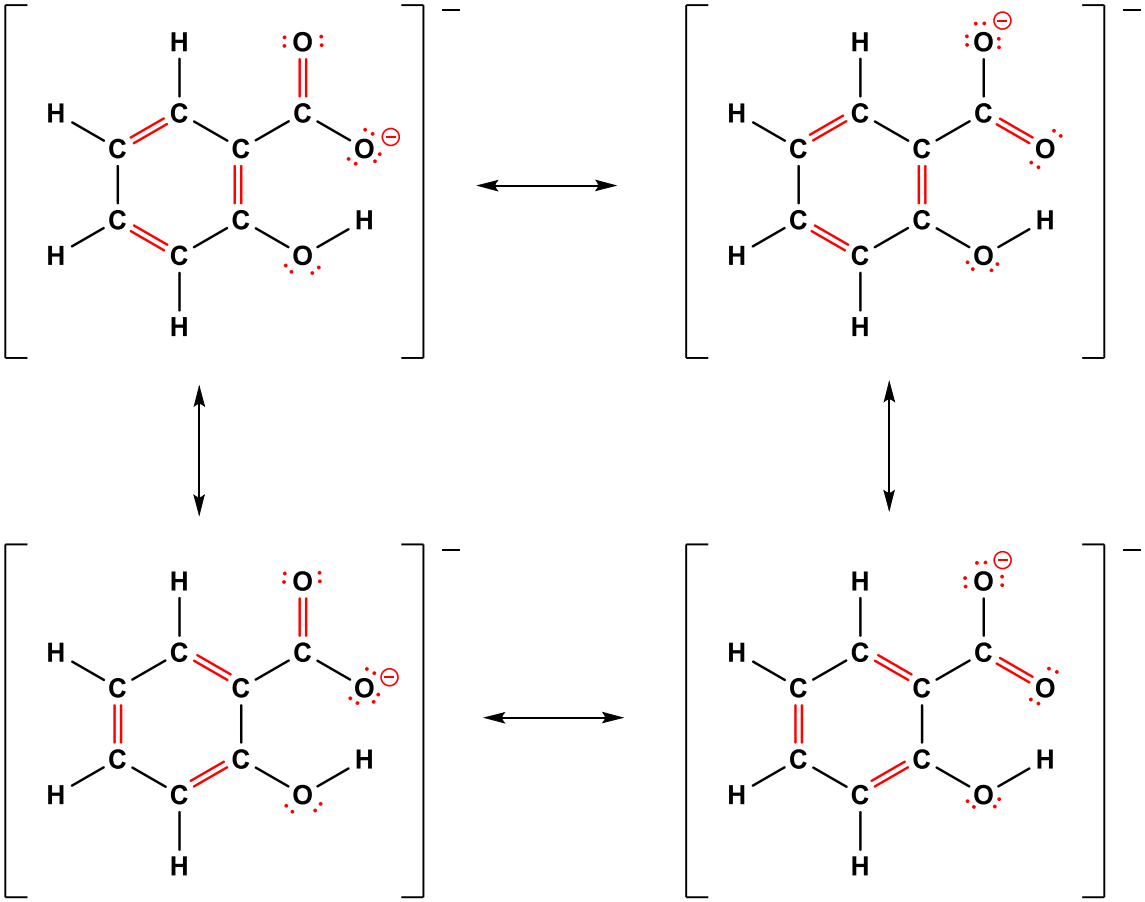
PART II. Short Answer Questions [30 marks total]

Write all answers ***in the appropriate box on the separate bubble sheet***.

Only answers given on the bubble sheet will be marked. You may use the templates provided here for rough work.

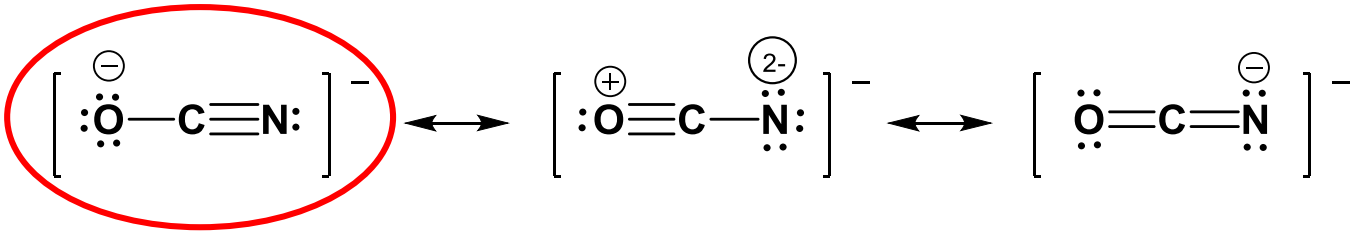
18. **[4 marks]** Complete the skeletal structures of the salicylate ion to give four best Lewis resonance structures. Show all lone pairs of electrons as pairs of dots and all additional bonds as lines. Write any non-zero formal charges on the appropriate atoms.

Templates for rough work:



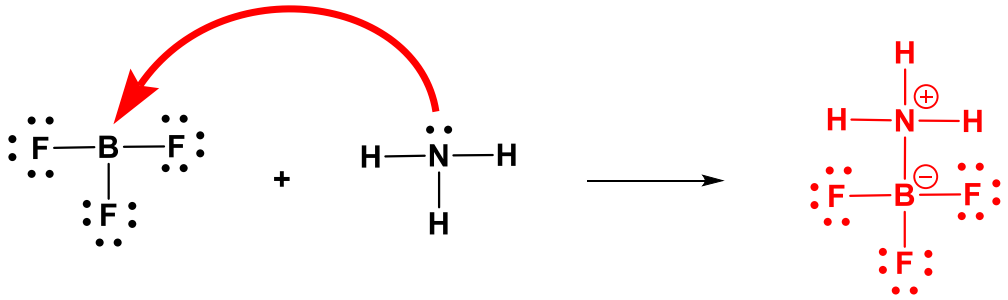
19. **[4 marks]** Complete the skeletal structures of the cyanate ion, $[OCN]^-$, to give three valid Lewis resonance structures. Show all lone pairs of electrons as pairs of dots and all additional bonds as lines. Write any non-zero formal charges on the appropriate atoms. <u>Circle the best Lewis structure.</u>

Templates for rough work:



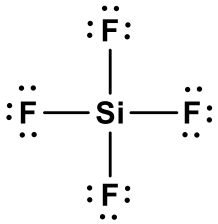
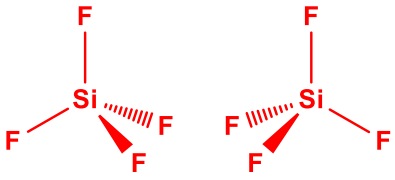
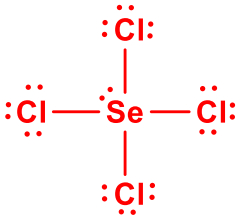
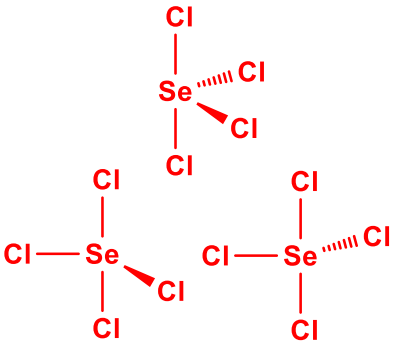
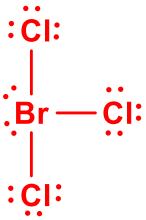
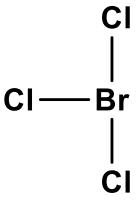
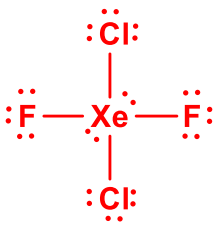
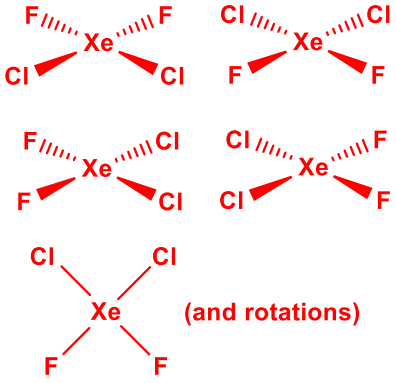
20. **[3 marks]** Boron trifluoride, BF_3, and ammonia, NH_3, react to form a single product. The Lewis structures for BF_3 and NH_3 are shown below. Draw the best Lewis structure for the product, including all formal charges and lone pairs, and <u>draw a curved arrow</u> to show how the product is formed from the two reactants.

Template for rough work:



21. **[9 marks]** Complete the table for the following molecules <u>on the separate bubble sheet.</u> The central atom in each molecule is underlined. Information on the polarity is given. For Lewis structures, be sure to show all lone pairs of electrons as pairs of dots and to indicate any non-zero formal charges on the appropriate atoms.

    Template for rough work:

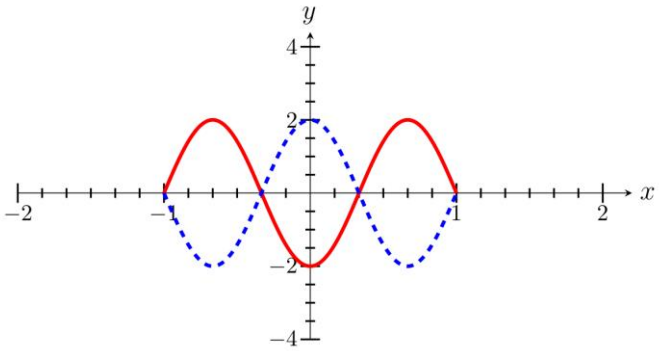
	Best Lewis Structure	Perspective Diagram	Molecular Shape
<u>Si</u>F_4 **(Nonpolar)**			Tetrahedral
<u>Se</u>Cl_4 **(Polar)**			**seesaw**
<u>Br</u>Cl_3 **(Polar)**			T-shaped
<u>Xe</u>Cl_2F_2 **(Polar)**			Square Planar

22. **[4 marks]** Draw two sinusoidal functions, Function A and Function B, which satisfy the following conditions:

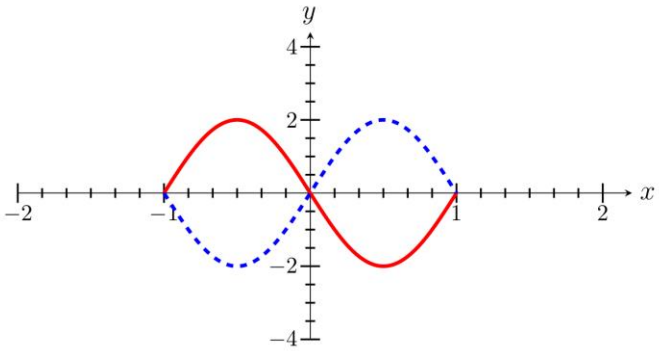
    i. Function A and Function B both represent a quantum particle confined in a one-dimensional box with edges at $x = -1$ and $x = +1$.
    ii. Function A and Function B both have amplitudes of 2.
    iii. Function A has exactly 2 nodes.
    iv. Function A represents a higher energy than Function B.
    v. Function A and Function B both represent excited states.

Templates for rough work:

Function A



Function B



Could plot either the solid red line or the dashed blue line for each graph (NOT both on the same graph).

23. **[6 marks]** Consider the first six states (i.e. $n = 1, 2, 3, 4, 5, 6$) of an electron in a one-dimensional box with length L. **Using each state only once**, determine an n value that matches each statement. Bubble in your final answers in the appropriate box on the bubble sheet.

(a) A state where the wavefunction has a wavelength of $\lambda = L/3$ is: $n =$ ___**6**_____

(b) The state where the wavefunction has the lowest kinetic energy is: $n =$ ___**1**_____

(c) The state with exactly 4 most probable positions of finding the electron is: $n =$ ____**4**____

(d) A state where the average position is $x = L/2$ is: $n =$ ___**2 (all)**___

(e) A state with exactly 4 nodes in the wavefunction is: $n =$ ___**5**_____

(f) A state where one of the most probable positions is $x = L/6$ is: $n =$ ___**3**_____

END OF EXAMINATION

Supplementary Information

Potentially useful constants and conversion factors

1 Hertz = 1 Hz = 1 s^{-1} = 10^{-6} MHz

1 m = 10^{6} μm = 10^{9} nm = 10^{10} Å = 10^{12} pm

1 J = 1 kg m^2 s^{-2}

h = Planck's constant = 6.626 × 10^{-34} J s

N_A = Avogadro's number = 6.022 × 10^{23} mol^{-1}

c = speed of light = 3.00 × 10^{8} m s^{-1}

1 amu = 1 u = atomic mass unit = 1.66 × 10^{-27} kg

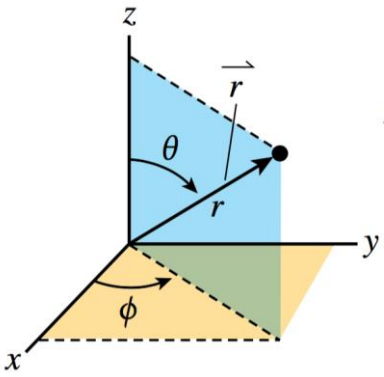
electron mass = 9.11 × 10^{-31} kg

proton mass = 1.67 × 10^{-27} kg

1 eV = 1.60 × 10^{-19} J

a_o = Bohr radius = 0.53 Å

R_H = Rydberg constant = 2.18 × 10^{-18} J



Spherical polar coordinates

$x^2 + y^2 + z^2 = r^2$

$x = r \sin\theta \cos\phi$

$y = r \sin\theta \sin\phi$

$z = r \cos\theta$

Potentially useful formulae

$v = \lambda\nu$

$\lambda = h/p = h/mv$

$E_K = mv^2/2$

$\Psi_n(x) = (2/L)^{1/2} \sin(n\pi x/L)$ $(n = 1, 2, 3...)$

$E_n = h^2n^2/8mL^2$

$E_n = -(2.18 \times 10^{-18}\ J)\ Z^2/n^2$

$f(x) = A\sin(2\pi x/\lambda)$

$E = mc^2$

$E = h\nu$

$E_K = E_{light} - E_{binding} = h(\nu - \nu_o)$

PERIODIC TABLE OF THE ELEMENTS

Group 1	2											13	14	15	16	17	18
1 H 1.008																1 H 1.008	2 He 4.003
3 Li 6.941	4 Be 9.012											5 B 10.811	6 C 12.011	7 N 14.007	8 O 15.999	9 F 18.998	10 Ne 20.179
11 Na 22.99	12 Mg 24.305	3	4	5	6	7	8	9	10	11	12	13 Al 26.982	14 Si 28.086	15 P 30.974	16 S 32.064	17 Cl 35.453	18 Ar 39.948
19 K 39.098	20 Ca 40.08	21 Sc 44.956	22 Ti 47.9	23 V 50.941	24 Cr 51.996	25 Mn 54.938	26 Fe 55.847	27 Co 58.933	28 Ni 58.7	29 Cu 63.546	30 Zn 65.38	31 Ga 69.72	32 Ge 72.59	33 As 74.922	34 Se 78.96	35 Br 79.904	36 Kr 83.8
37 Rb 85.468	38 Sr 87.62	39 Y 88.906	40 Zr 91.22	41 Nb 92.906	42 Mo 95.94	43 Tc "(98)"	44 Ru 101.07	45 Rh 102.9	46 Pd 106.4	47 Ag 107.87	48 Cd 112.41	49 In 114.82	50 Sn 118.69	51 Sb 121.75	52 Te 127.6	53 I 126.9	54 Xe 131.3
55 Cs 132.9	56 Ba 137.33	57 La* 138.91	72 Hf 178.49	73 Ta 180.95	74 W 183.85	75 Re 186.21	76 Os 190.2	77 Ir 192.22	78 Pt 195.09	79 Au 196.97	80 Hg 200.59	81 Tl 204.37	82 Pb 207.2	83 Bi 208.98	84 Po "(209)"	85 At "(210)"	86 Rn "(222)"
87 Fr 223	88 Ra 226.03	89 Ac# 227.03	104 Rf "(267)"	105 Db "(268)"	106 Sg "(271)"	107 Bh "(272)"	108 Hs "(270)"	109 Mt "(276)"	110 Ds "(281)"	111 Rg "(280)"	112 Cn "(285)"	113 Nh "(284)"	114 Fl "(289)"	115 Mc "(288)"	116 Lv "(293)"	117 Ts "(294)"	118 Og "(294)"

*	58 Ce 140.12	59 Pr 140.91	60 Nd 144.24	61 Pm 145	62 Sm 150.4	63 Eu 151.96	64 Gd 157.25	65 Tb 158.92	66 Dy 162.5	67 Ho 164.93	68 Er 167.26	69 Tm 168.93	70 Yb 173.04	71 Lu 174.97
#	90 Th 232.04	91 Pa 231.04	92 U 238.03	93 Np 237.05	94 Pu 244	95 Am 243	96 Cm 247	97 Bk 247	98 Cf 251	99 Es 252	100 Fm 257	101 Md 258	102 No 259	103 Lr 260